Numerical Modelling and Experimental Measurements of Pesticides Dispersion in a Naturally Ventilated Greenhouse

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Keywords: tracer gas, numerical simulation, turbulence model, aerial pollutants

Abstract

In the present study a commercial CFD code was used in order to investigate the dispersion of a pesticide inside an arch type tunnel greenhouse with continuous side vents. The greenhouse was cultivated with a tomato crop planted in double rows, which, during the period of measurements had a height of 1.5 m. In parallel, measurements were carried out in order to experimentally determine the decay rate of pesticide concentration. Air samples were continuously taken at seven points inside the greenhouse (six air pumps and one gas analyser). In the 3D numerical model calculations were done for several wind directions and wind speeds, using the experimental values as boundary conditions. The final solution for every case of wind direction and wind velocity was obtained, firstly by a converge solution under steady – state condition; and secondly by an unsteady one, where at the time which equals to zero the air volume in the experimental greenhouse was considered to contain a mixture consisting of air and the used pesticide. The simulation results that were in the same order of magnitude with the experimental values only during the first 5-6 minutes of unsteady solution and only qualitatively good agreement for the rest time, while the decay process was simulated. Even if different wind characteristics, as boundary conditions, were introduced in the CFD model every minute, the agreement remained in a qualitative level, showing that the concentration of the pesticide inside the greenhouse is a function not only of the greenhouse ventilation rate but also of the pesticide evaporation-volatilisation rate from the greenhouse crop, soil and cover surfaces. As the simulation model almost always underestimates the concentration levels inside the greenhouse, more investigation has to be carried out in order to obtain better agreement between measured and estimated values of pesticide concentration inside the greenhouse.

INTRODUCTION

Pesticides belong to a wide group of chemicals of growing public health concern. Indeed, leukemia, non-Hodgkin's lymphoma and other cancers (Richter and Chlamtac, 2002), neurologic pathologies, respiratory symptoms (Salameh et al., 2003) and hormonal and reproductive abnormalities have been associated with pesticide exposure, mostly in case-control and ecological studies. A variety of pesticides is used in greenhouses to maintain high crop yields. An important side effect of the use of pesticides is the potential harm they can cause to humans and the environment. In recent years there has been an increasing concern that pesticides constitute a risk to the general human population through residues in the food supply (Bolognesi, 2003).

Pesticide residue evaluation in agricultural products and their dispersion to the environment can be measured by analytical methods. These experimental approaches are often limited by high costs, the time involved, and analytical detection limits. An

Proc. IS on Greensys2007
Eds.:S. De Pascale et al.
Acta Hort. 801, ISHS 2008

alternative approach to the classical laboratory analysis is pesticide fate and exposure modelling. A greenhouse tomato model developed by Anton et al. (2004), describes human exposure pathways for pesticides applied in greenhouses in Spain. For all pesticides, exposure via tomato intake represented the most important exposure pathway for humans. Pesticide exposure of indoor workers, and specifically exposure of greenhouse workers, has been assessed in numerous studies, by means of static and personal air samplers, skin pads and hand wipes or washes (Aprea et al., 2002).

Concerning specific pesticides, analysis of lindane and three endosulfan isomers in greenhouse air indicates that 24 h after application, concentration levels of 8.5% and 7.5% of the initial values, respectively, remained in the air (Vidal et al., 1997). The results also showed that the dissipation rate and the decline process were influenced by parameters such as temperature and relative humidity. An application of metamidophos in a greenhouse showed that the concentration decreases dramatically the first hour after application, but in the following hours the diminution was slower and even 52 h after application metamidophos was detected in the air (Egea et al., 1998).

In addition, understanding the process of emission and dispersion of pesticides from greenhouses will be a useful tool for responsible authorities in order to specify the frame of pesticide legislation, integrating all necessary precautions to protect workers, bystanders, surrounding communities and the environment (FAO, 2002).

During the last years an increasing use of numerical techniques gave the researchers the ability to simulate transfer phenomena, which occurred in agricultural buildings, considering structure details of the building and its ambient environment. Computational Fluid Dynamics (CFD) was used to predict the concentration of ammonia gas from an animal building by Ouinn et al. (2001). At a distance of more than three building heights downstream, the predictions from model were satisfactory even if some problems occurred concerning the variation of wind direction and the use of turbulence model. CFD models have been used successfully in greenhouses ventilation studies (Campen and Bot, 2003; Bartzanas et al., 2004). Despite the limitations of simulation models (Abraheem et al., 2001) the CFD could be a power tool in order to optimize the use of application of pesticides, understanding their dispersion to greenhouse's environment. In the frame of the development of a sustainable agriculture the necessity of combination ecology and technology is crucial in order the future target of 'zero-application' of agrochemicals to be achieved (Jongebreur, 2000).

The objective of the present study is, to validate a commercial CFD code against experimental measurement and use it later in order to investigate the dispersion of a pesticide inside an arch type tunnel greenhouse with continuous side vents.

MATERIALS AND METHODS

Experimental Greenhouse, Crop and Measurements

The experiments were performed in an arch type greenhouse, N-S oriented (36º declination from north 0º), located at the University of Thessaly near Volos, (Latitude 39º44′, Longitude 22º79′, Altitude 85 m) on the continental area of Eastern Greece, during the summer of 2005. The greenhouse was covered by a double inflated polyethylene film on the roof and by glass on the sidewalls and gables. The geometrical characteristics of the greenhouse were as follows (Fig. 1a): eaves height =3 m; ridge height = 4.65 m; total width = 10 m; total length = 30 m; ground area A_g =300 m^2 and volume V =1237 m^3. The greenhouse was equipped with two side flap vents located at a height of 1.5 m above the ground with a maximum opening area of 13.5 m^2 (30 m length × 0.45 m height) for each. The prevailing wind of the region has a N-S direction. The greenhouse was occupied by a tomato crop which, during the period of measurements, had an average height of about 1.5 m. The tomato crop (cv. Condesa) was planted in the soil, along greenhouse length, in March 2005 and the plant density was 2 plants m^{-2}. The plants were spaced 0.65 m apart with row spacing of 0.8 m. Water and fertilizers were supplied by a drip system, which was automatically controlled by a fertigation computer.

The plants were grown following the one stem technique.

Pesticide was applied as diluted water emulsion of the formulation Scala 40SC early the morning by spraying 1.5 L water emulsion containing 120ml of the formulation product with a low volume sprayer. Pesticide concentration in air was measured after air sampling in Supelpack-2 solid sorbent, liquid extraction and determination by gas chromatography with NP detector according Tsiropoulos et al. (2006).

Numerical Model

The commercially available computational fluid dynamics code Fluent was used, in this study, to obtain airflow and temperature patterns. Fluent (Fluent, 1998) is a general purpose commercial CFD package that uses the finite volume numerical scheme to solve the equations of conservation for the different transported quantities in the flow (mass, momentum, energy, water vapour concentration). Further information concerning the set-up of the numerical model can be found in Kittas et al. (2005).

The experimental greenhouse and the ambient environment were designed using the geometrical processor Gambit 1.1. The simulation domain extends 198 m in the x-direction, 193 m in the z-direction and 30 m in the y-direction (Fig. 1a). The density of mesh was checked through many attempts in order to combine the solution accuracy with the time needed for the convergence. The final solution scheme was consisted of 464730 cells and the equations of conservation were solved numerically.

The solution was obtained in two steps: firstly by a steady state solution using the measured wind characteristics as boundary conditions and secondly by an unsteady one where at time equals to zero the ventilator openings where opened and the concentration level of pesticide ‘pyrimethanil’ inside the greenhouse was determined. The initial concentration of pyrimethanil (Sapounas and Nikita-Martzopoulou, 2004) inside the greenhouse was set to 94.11 µg/L that corresponds to the average concentration measured at 7 positions inside the greenhouse (Fig. 1b). According to the initial concentration of pyrimethanil and its density, the mass fraction of pesticide was calculated and set to 7.6819×10^{-5}. Firstly, the boundary conditions concerning the wind were set equal to the average experimental values of the respective time periods. Then, the boundary conditions changed every computational minute in order to simulate in the most detailed way the influence of the wind on greenhouse climate (Table 1).

RESULTS AND DISCUSSION

The numerical and experimental results (Fig. 2) show a good qualitative agreement only for the first minutes of simulations (correlation coefficient between numerical and experimental values ranged from 0.70 for position 6, to 0.95 for position 5). The rate of pyrimethanil concentration decrease changed rapidly mainly after the first 5-6 minutes, something that was not obtained by the simulations. This could be explained by the fact that while the pesticide is sprayed in the greenhouse air, one part remains in the air and the rest directly deposits to the plants and soil surface and to the structural elements of the greenhouse. The droplets of the pesticide that deposit inside the greenhouse are then evaporated and the pesticide is volatilised; and released again to the greenhouse air, representing in this way an additional source of pesticide. This source is not taken into account by the numerical model.

The pesticide concentration inside the greenhouse decreases against time by a different rate in the several measuring positions. In Figure 3, an increase of the pesticide concentration can be noticed between t = 8:26 and t =8:28. This can be attributed to the change of wind direction and is especially noted in positions where recirculation of air flow occurs.

The wind characteristics dominate the phenomenon of dispersion of pesticide around the greenhouse environment. In Figure 4 the concentration of pyrimethanil inside the experimental greenhouse and in the outside environment 1.5 m above the ground was calculated for a N-S wind direction a) 30 sec, b) 1 min, c) 2 min, and d) 4 min after vents opening. The concentration of the pesticide decreased first in the windward part of the greenhouse and afterwards in the rest of the greenhouse volume. This distribution is due to the air movement inside the greenhouse. When air flows in parallel to the greenhouse long axis, the air enters in the greenhouse through the leeward side and exits through the windward side. Similar airflow pattern was measured in a greenhouse with a continuous roof vent (Boulard et al., 1997), and is also observed both experimentally and numerically in the same to the current study experimental greenhouse when, instead of the pesticide, a well known (N_2O) tracer gas was used (Kittas et al., 2006).

The wind direction has a major role in the dispersion of pesticide in the ambient environment. As can be seen in Figure 5, a N-S direction transfers the pesticide outside of the greenhouse and disperse it in the nearby greenhouses and buildings. The distance in which the pesticide can be found in high concentrations depends on the initial concentration of the pesticide inside the greenhouse and on the wind velocity.

CONCLUSIONS

Numerical and experimental results concerning the emission of a pesticide (pyrimethanil) inside and outside an experimental greenhouse with a tomato crop were presented and analyzed. Good overall agreement was found between the numerically and experimentally obtained results, especially during the first minutes after vents' opening. During the first minutes of ventilation, the decrease of the concentration of the pesticide depends on air flow, and on vapour pressure differences between the incoming air and the greenhouse air that contains the pesticide. After the first minutes, when a part of the pesticide has been dispersed to the environment, the connection forces between the pesticide and mainly the plant leaves have a key role to the pesticide concentration in the air. The pesticide is dispersed from crop surface, where has overlaid after pesticide application, till the shearing forces become strong enough to stop any farther pesticide dispersion. Accordingly, through this approach, the crop behaves as a 'source term' for the pesticide.

The dispersion-volatilisation rate of the pesticide from the crop to the air and its variation through time remains an open question which will be faced during oncoming research.

ACKNOWLEDGMENTS

The project is co-funded by the European Union - European Social Fund & National Resources - EPEAEK II within the framework of 'Pythagoras' projects.

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Tables

Table 1. Boundary conditions used in the CFD model.

Model or parameter	Settings
East	Pressure outlet
North	Velocity inlet (profile)
West	Velocity inlet (profile)
South	Pressure outlet
Turbulent Intensity	5
Turbulent length scale	4
Plants	Porous media
Turbulence model	k-epsilon realizable
Species model	2 species (air + pyrimenthanil)
Temperature	28 ºC
Mass fraction of pyrimethanil	7.6819×10^{-5}

Figures

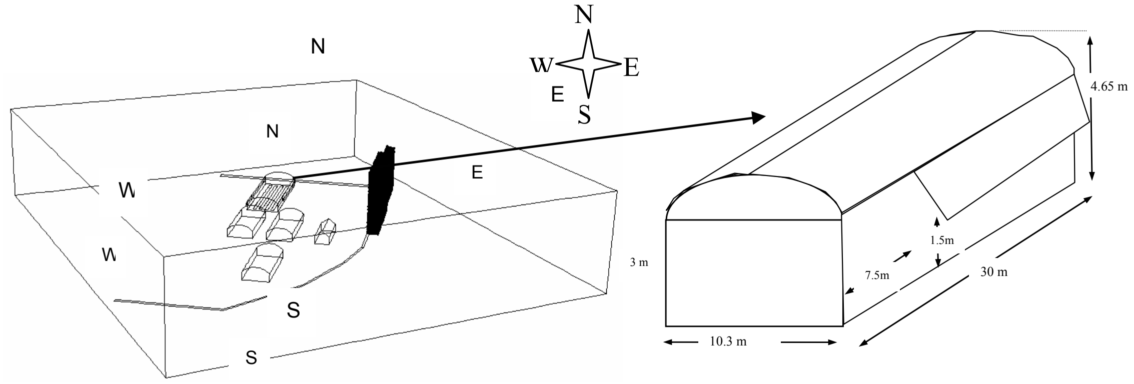


Fig. 1a. Experimental greenhouse, its ambient computational domain.

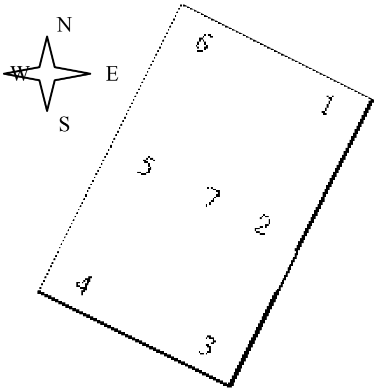


Fig. 1b. Measuring positions (1-7) inside the experimental greenhouse.

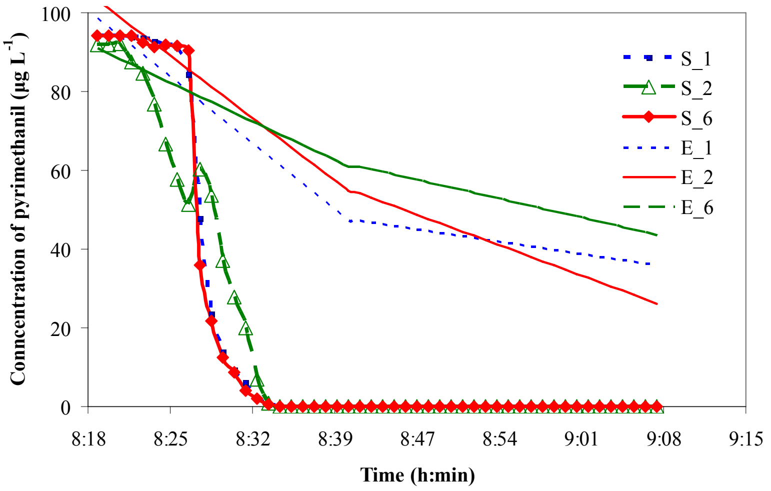


Fig. 2. Simulated (S_1, S_2, S_6) and experimental (E_1, E_2, E_3) values of pyrimethanil concentration, at positions 1, 2 and 6, for 50 minutes after vents' opening.

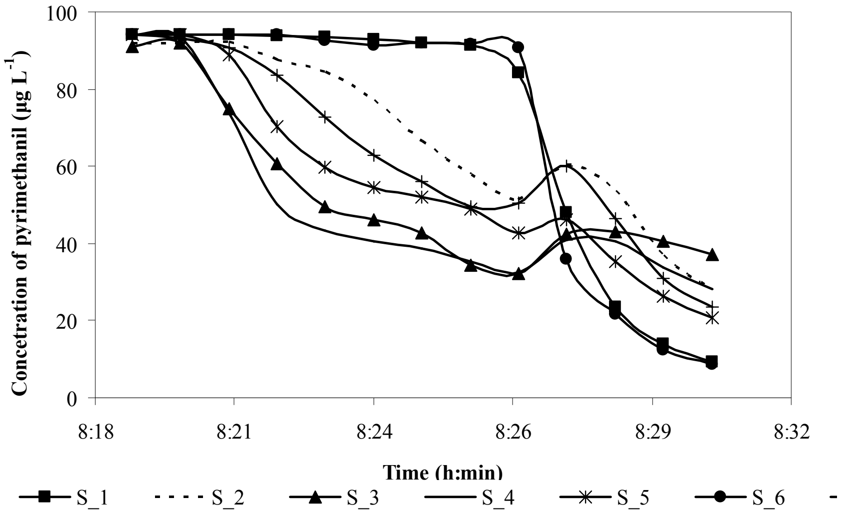
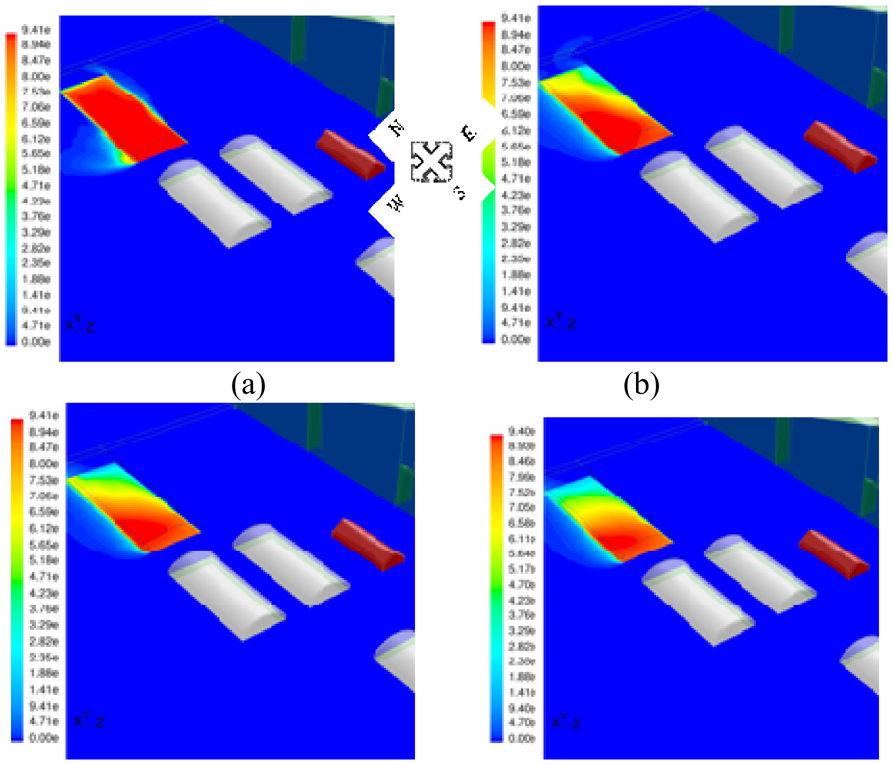


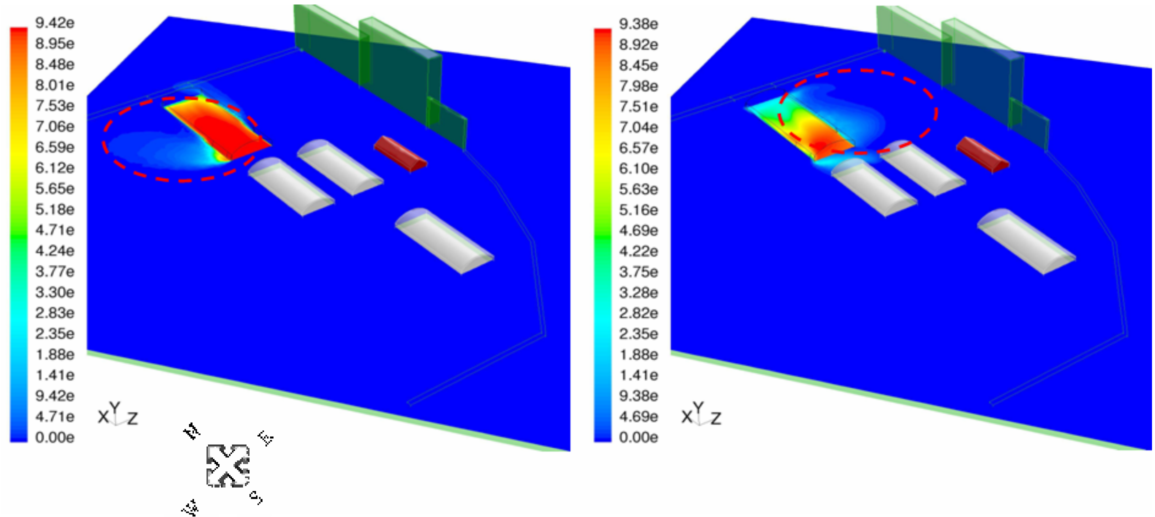
Fig. 3. Simulated values of pyrimethanil concentration at positions 1 - 7 inside the greenhouse, for 13 minutes after vents' opening. Vents opening took place at 8:18.



(a) (b)

(c) (d)

Fig. 4. Simulated contours of pyrimethanil concentration inside the experimental greenhouse (a) 30 s, (b) 2 min., (c) 3 min., and (d) 4 min. after pesticide application for a S-N wind direction.



(a) (b)

Fig. 5. Simulated contours of pyrimethanil concentration inside the experimental greenhouse and at the ambient environment. Effect of wind direction on the dispersion of pesticide (a) E-W wind direction; and (b) N-S wind direction.